

THE ROBOTICS AND INTELLIGENT MACHINES (RIM) INITIATIVE AT THE U.S. DEPARTMENT OF ENERGY

— *Basis* —

DOE's Need for Robotics and Intelligent Machines is Broad-based

The U.S. Department of Energy (DOE) is faced with a complex and diverse array of demands resulting from its missions. From ensuring the safety and reliability of the enduring nuclear stockpile, to protecting the safety of its employees, to cleaning-up and protecting the environment at highly complex and contaminated sites, no other Federal agency or private sector company matches DOE's range of needs and breadth of responsibilities for manufacturing, environmental management, materials accountability, and scientific leadership. Among its many challenges, DOE must:

- Lower the cost of its operations in the face of inflationary and other pressures on its budget;
- Remove its workers from hazardous environments as a result of rising safety awareness and the availability of enabling technologies;
- Reduce the environmental impact of its operations; and
- Find the means to perform operations that are necessary, but impossible for humans to perform, and for which no alternatives currently are available.

One of the most promising solutions to these challenges lies in the widespread introduction and use of robotics and intelligent machines (RIM). Over the next two decades, requirements for facility decontamination and decommissioning, site characterization and remediation, weapons system re-manufacturing and dismantlement, and materials disposition will change significantly, most probably in a climate of decreasing budgets and tight resources. Furthermore, many tasks required of the DOE are simply too dangerous to be performed by humans. This combination of forces will leave DOE little choice but to turn to the emerging capabilities of RIM—capabilities that are just now demonstrating sufficient flexibility, adaptability and “intelligence” to meet a sizeable portion of DOE's needs.

DOE Has Developed a Plan for Addressing Its Needs

In 1998, the DOE, working with its laboratories and with representatives of other Federal agencies, developed a roadmap for RIM R&D that defined specific DOE mission-related objectives and described a plan for developing the technology required to meet these objectives. Since completion of the roadmap, momentum for a more concerted effort in RIM has grown. Based on the goals in the roadmap, DOE developed an agency-wide RIM R&D Plan in 1999, and has defined the scope and operation of a new Initiative in RIM that follows the path outlined in the Roadmap.

DOE Has Demonstrated that it Can Successfully Plan, Develop, Deploy and Operate RIM Systems

Emerging RIM technologies are beginning to provide DOE with dramatically enhanced capabilities and the adaptability needed to address its multiplicity of needs, which include specific desires for:

- Cost-effective, small-lot weapon re-manufacturing;
- Safe, reliable and cost-effective characterization, decontamination, decommissioning, and remediation of “unstructured” sites;
- Secure and safe nuclear materials surveillance and monitoring of increasing quantities of Special Nuclear Materials from the retired nuclear weapons stockpile; and
- Reduction of secondary waste generation.

In common with some other efforts, both within and external to the government, DOE had mixed success in its efforts in the late 1980's and early 1990's to apply RIM technology to its operations. Many of those early robotics systems did not meet the grand expectations set for them a decade earlier—they were a technology before their time. In effect, RIM's early shortcomings were the result of a technology base that was not sophisticated or mature enough to perform the tasks that were required and desired by its many proponents. Consequently, in the 1990's DOE launched a prototype of the RIM Initiative that developed a needs-based, focused, science and technology foundation for RIM, and then deployed this emerging RIM S&T into cost-effective systems operating at the DOE's plants and sites. This approach, with its emphasis on needs-based research and then continuity and integration from *research* to *development* to *application* and *deployment*, proved to be successful.

In the last several years, RIM systems have entered continuous successful operation in the DOE, averting costs of greater than \$100M while accomplishing tasks that could not have been done by any other means, human or mechanical. For example, disassembly of explosive components at the DOE's Pantex plant is now handled by robots, as is contaminated waste being retrieved from gunite waste tanks at Oak Ridge National Laboratory. Tackling these and other typical DOE tasks frequently is not possible using standard, commercially available equipment (although these are used whenever it is possible) because the environments in which the equipment must operate are too hostile, often involving high levels of radioactivity, explosives, corrosives, etc., and because they are usually “one-of-a-kind,” or small lot operations for which built-to-specification systems are required. The intention of DOE's RIM Initiative is to continue this focus on areas of research, development and deployment that will accelerate RIM's capabilities to address DOE's operational needs, as opposed to R&D for deployment into private sector operations. The RIM Initiative's science and technology program is motivated solely by the differentiating needs of DOE applications; specifically, unstructured and small lot operations, especially those for which high reliability and safety are required, (e.g., processes involving radioactive, explosive or toxic materials, and/or the re-manufacture of high-reliability nuclear weapon components.)

Advances in Underlying and Related Technologies are Enabling the Accelerated Use of RIM in DOE Operations

RIM technology is coming of age now, at the beginning of the 21st Century. In large part this is because advances in the fundamental technologies that underlie RIM have also come into their own. For example, computing speed, improving as predicted by Moore's law, has been doubling every 18-24 months and is now capable of handling the algorithms and software that constitute RIM's "intelligence." Similarly, new advances in communications technology, micro-engineering, and artificial intelligence are contributing to the effectiveness and versatility of RIM.

The science and technology program of the RIM Initiative involves research development and deployment of systems composed of machines, computers, sensors, and system "intelligence" codified in the form of mathematics, physics, computer and information science, rules and computational models. Together, these components provide the flexibility, adaptability and intelligence that are making the new RIM systems viable solutions to some of DOE's most intractable problems. Underscoring this point, mounting evidence from systems currently in operation within DOE provide evidence that modern software engineering processes and reliable microcomputer and communication technologies are enabling machines to make decisions based on algorithms and sensed information without endangering the safety of the operations in which they are engaged. Indeed, in many cases operational safety is being improved.

DOE Scientists are Performing World-class Research in RIM

The RIM R&D that was performed to support the successes of the 1990s is yielding world class results. Today, DOE is poised to simultaneously improve its operations and significantly advance the state-of-the-art of RIM. DOE-sponsored research in the four basis technology areas of RIM—perception, action/motion, reasoning and integration systems—is yielding new insight as well as more tangible rewards, including eight R&D 100 awards and 44 patents. DOE scientists and engineers have successfully formed numerous agreements to work with other Federal agencies and created more than 40 Cooperative Research and Development Agreements (CRADAs) with industry. Many of these technologies, whose development was initiated in response to specific DOE needs, are now being commercialized by the private sector.

A RIM Initiative Will Help the DOE Laboratories Attract and Retain World-class Scientists

By its nature, RIM R&D demands the contribution of a wide crosscut of technological disciplines. Revolutionary advances in its four basis technology areas—perception, reasoning, action/motion, and integration systems—will require outstanding researchers in technical disciplines including computer science, mathematics, physics, and environmental, electrical and mechanical engineering. The scientific and engineering challenges being encountered in developing the next generation of RIM are comparable to those of putting a man on the moon or of the Manhattan Project, and are the type of challenges that appeal to the best of the DOE laboratories' current staff and attract the best graduates of our Nation's universities.

DOE's RIM Initiative Will Involve Industry, Academia and DOE Laboratories

In November 1997, Senators Lieberman, Snowe, Bingaman, Domenici, and D'Amato, along with Congressmen Franks and Meehan, sent a letter to the Secretaries of Defense, Energy, and Commerce, the Administrator of NASA, and the Director of the National Science Foundation endorsing an eight-point program to advance state of the art in robotics and intelligent machines. The letter recognized that the U.S. is the world leader in enabling technologies such as software,

sensors and controls, and is on the cusp of major advances that may allow the U.S. to regain its dominant position in the robotics and intelligent machines industry. The letter urged U.S. Government agencies and laboratories to work in partnerships with U.S. companies and universities to enable the United States to take the lead in this industry.

DOE recognizes that some of the most fundamental research and development in RIM has been performed at universities, and also that industry is expected to supply almost all of the hardware—robots, computers, and instrumentation—that will be deployed at DOE plants, sites and facilities. Thus, the RIM Initiative anticipates that both groups will work in partnership with the DOE laboratories to address, on the one hand, areas that have been significantly under-researched such as cooperative robotics and programming environments for intelligent machines, and on the other hand, to transfer these and other scientific and technological developments funded by the Initiative to industry.

But will U.S. industry be interested in partnerships of this sort? The answer is “yes,” for the following reasons: the technology that DOE will develop will allow robots to work cost-effectively and productively in “small lot” and “unstructured” environments. While industrial robots have operated cost-effectively for more than a decade in mass production situations, they have had difficulty penetrating manufacturing operations in which only a limited number of products are built—a typical situation in many of DOE’s current manufacturing operations. This is because using today’s technology, not enough products are built over which to amortize the cost of setting up robot workcells. However, the vast power of computing now available within the DOE permits the creation of robot workcells at much lower costs and with much more adaptable abilities. A very valuable outcome of the RIM Roadmap was the understanding that the technology base needed for DOE’s small lot manufacturing is very similar to that needed for DOE’s highly unstructured working environments such as the remediation of contaminated waste sites.

DOE Initiative-sponsored RIM science and technology will benefit the domestic RIM industry by enabling the introduction of intelligent systems to large numbers of small- and medium-sized companies. Furthermore, it is anticipated that DOE’s investments will expand the use of RIM technologies by large manufacturers by providing them with more flexibility in their production; e.g., the cost and time of changeover between product designs will be vastly reduced. Finally, DOE’s use of these technologies will give industrial suppliers and users confidence in the usefulness and market for RIM.

In conclusion, the RIM Initiative is designed to enable DOE to build on and integrate the strong science and technology base and record of success that underpins RIM today, and ensures that DOE will continue to link outstanding research to additional needs, and to the effective deployment of technology that will accelerate DOE’s ability to meet its national security, environmental quality and scientific leadership missions. RIM will not only change the way DOE accomplishes its missions over the next several decades; advanced RIM technologies will fundamentally change the manner in which people use machines. New robotic systems, fueled by improvements in computing, communication and microengineered technologies, will transform many of humankind’s most difficult tasks.